REPORT No. 307

THE PRESSURE DISTRIBUTION OVER THE HORIZONTAL AND VERTICAL TAIL SURFACES OF THE F6C-4 PURSUIT AIRPLANE IN VIOLENT MANEUVERS

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SUMMARY

This investigation of the pressure distribution on the tail surfaces of a pursuit airplane in violent maneuvers was conducted by the National Advisory Committee for Aeronautics at the request of the Navy Bureau of Aeronautics for the purpose of determining the maximum loads likely to be encountered on these surfaces in flight. The information is a part of that needed for a revision of existing loading specifications to bring these into closer agreement with actual flight conditions. A standard F6C-4 airplane was used and the pressure distribution over the right horizontal and complete vertical tail surfaces was recorded throughout violent maneuvers. The results show that the existing loading specifications do not conform satisfactorily to the loadings existent in critical conditions, and in some cases were exceeded by the loads obtained.

An acceleration of 10.5 g. was recorded in one maneuver in which the pilot suffered severely; it is therefore indicated that the limits of the physical resistance of the pilot to violent maneuvers are being approached.

Navy specifications for the structural design of tail surfaces are included as an appendix.

INTRODUCTION

Due to lack of sufficient data on the loads and load distribution on airplane tail surfaces, specifications of the strength requirements for the empennage are made somewhat arbitrarily and are changed now and then as surfaces which have been designed to meet the requirements fail in some condition of flight. The present specifications are based on certain experimental data obtained in the wind tunnel and in flight (see Bibliography), but this information is quite incomplete and does not furnish a satisfactory basis for the formulation of design rules. The most important of this previous work are the complete pressure distribution measurements on the tail surfaces of a JN-4 in steady and accelerated flight, the pressure measurements on single tail ribs of the VE-7 and TS airplanes at Langley Field, and the pressure distribution measurements on the right stabilizer of the VE-7 at McCook Field. The first of these is becoming less and less useful as airplanes are being made faster and more maneuverable and the others are not sufficiently complete to be of much value.

It was the aim in the present investigation to determine the complete distribution of pressure on all of the tail surfaces of a high-speed airplane in the maneuvers most likely to impose the highest loads on the tail structures, so that the existing specifications could be changed to conform more closely with the conditions likely to be experienced in flight. It was contemplated, further, to determine the loads on several types of balanced rudders and to obtain, simultaneously with the pressure records, accelerations in the X, Y, and Z directions at the center of gravity and at the tail. Unfortunately, the airplane was available for such a limited time that this program could not be entirely carried out, and the investigation was confined to the measurement of the maximum loads and pressures encountered on the standard tail surfaces in a number of violent maneuvers. Accelerations approaching the design load factor were obtained in several maneuvers and the pilot suffered rather severely at times from these high accelerations. In view, therefore, of this approach to the design load factor and to the limits of the physical resistance of the pilot, the loads obtained on the tail surfaces are indicative of the maximum tail loads which can be safely imposed on this type of airplane.

APPARATUS

THE AIRPLANE

The airplane used in these tests was a standard Navy F6C–4 (Curtiss "Hawk" with the Pratt & Whitney "Wasp" engine), (fig. 1), unaltered in any respect as to external form and internal structure. The moments of inertia about the Y and the Z axes were slightly increased since the recording manometer and the pressure tubes were installed aft of the center of gravity. The center of gravity itself was shifted back a small amount, but both of these alterations were slight, and their effects upon the results are negligible except in the dives, as will be explained
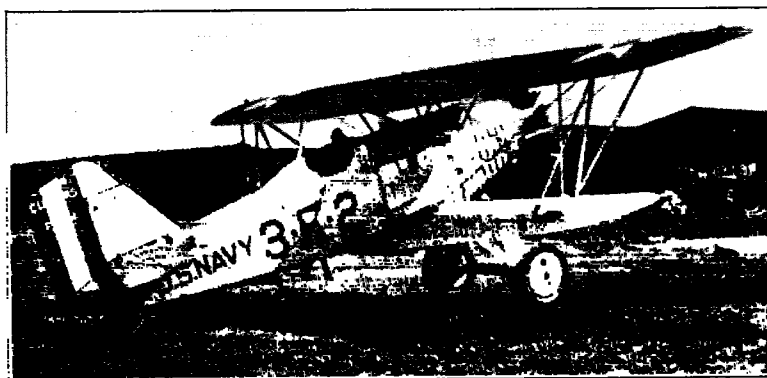

FIG. 1.—The F6C-4 airplane

later, inasmuch as they tend to balance each other in the critical loading condition. The effect, if any, is to decrease the downloads and to increase the uploads on the horizontal surfaces, and to increase the loads on the vertical fin and rudder.

THE TUBES AND ORIFICES

Pressure orifices of the type illustrated in Figure 2 were mounted on false ribs at the locations shown in Figure 3. There were two orifices at each location shown, one on the lower or right surface, and the other on the upper or left surface of the horizontal or vertical members, respectively. The pressures were transmitted through $\frac{3}{16}$-inch I. D. aluminum tubes which
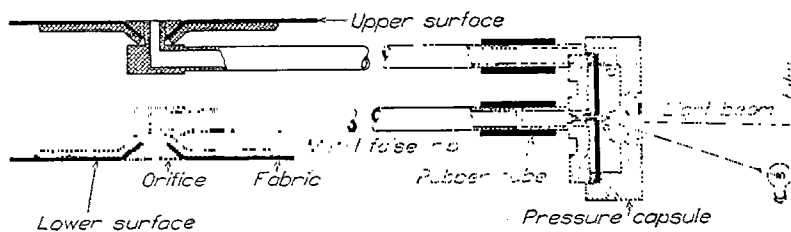

FIG. 2.—Diagram showing type of orifice and connection to capsule

were welded to the orifice blocks and which were connected to the manometer by means of short pieces of rubber tubing. The connections between the tubes in the fixed and movable elements of the tail also were made with rubber tubing so arranged that no kinks occurred at any angular displacement of the controls.

LOCATION OF ORIFICES

[Inches from center line of hinge

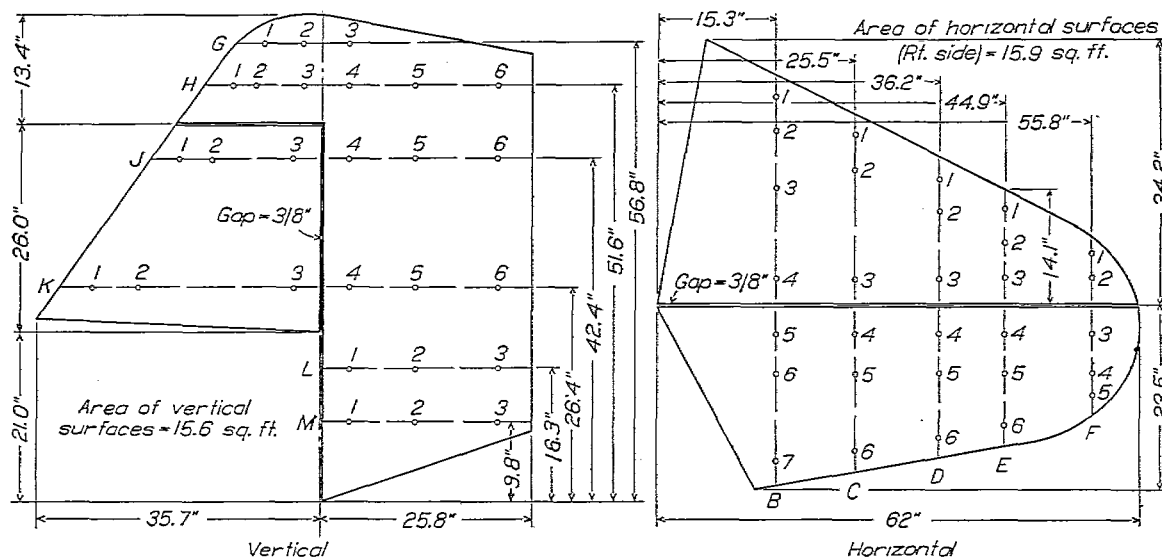| Rib Rib length	G 28.4″	H 40.8″	J 47.4″	K 58.9″	L 25.8″	M 25.8″	B 52.9″	C 46.0″	D 38.8″	E 33.0″	F 23.4″
1	−7.4	−11.4	−18.2	−29.3	3.3	3.3	−27.0	−22.1	−16.4	−12.4	−6.8
2	−2.8	−8.5	−13.9	−23.3	11.8	11.8	−21.8	−17.0	−11.7	−8.1	−3.6
3	3.3	−2.8	−3.8	−3.8	21.9	21.9	−14.7	−3.6	−3.6	−3.6	3.6
4		3.3	3.3	3.3			−3.6	3.6	3.6	3.6	8.6
5		11.8	11.8	11.8			3.6	8.6	8.6	8.6	12.0
6		21.9	21.9	21.9			8.6	18.5	16.9	15.3	
7							19.7				

FIG. 3.—Location of orifices on the F6C-4 tail surfaces

INSTRUMENTS

An N. A. C. A. type 60 recording multiple manometer (photographic type) was used to record the pressures. Briefly, this instrument consists of 60 pressure units or capsules, mounted on a metal case, as shown in Figure 4, and a film holder and driving mechanism. This manometer is the same in principle as the manometers used in previous tests (Reference 1), differing mainly from them in that it is capable of recording pressures from 60 stations instead of only 30.

In addition to the manometer, the following instruments were used: N. A. C. A. recording air-speed meter (Reference 2); N. A. C. A. control position recorder (Reference 3); and N. A. C. A. single component recording accelerometer (Reference 4). These instruments were all operated simultaneously on the same electrical circuit and controlled by the pilot through a button switch

FIG. 4.—N. A. C. A. type 60 recording multiple manometer
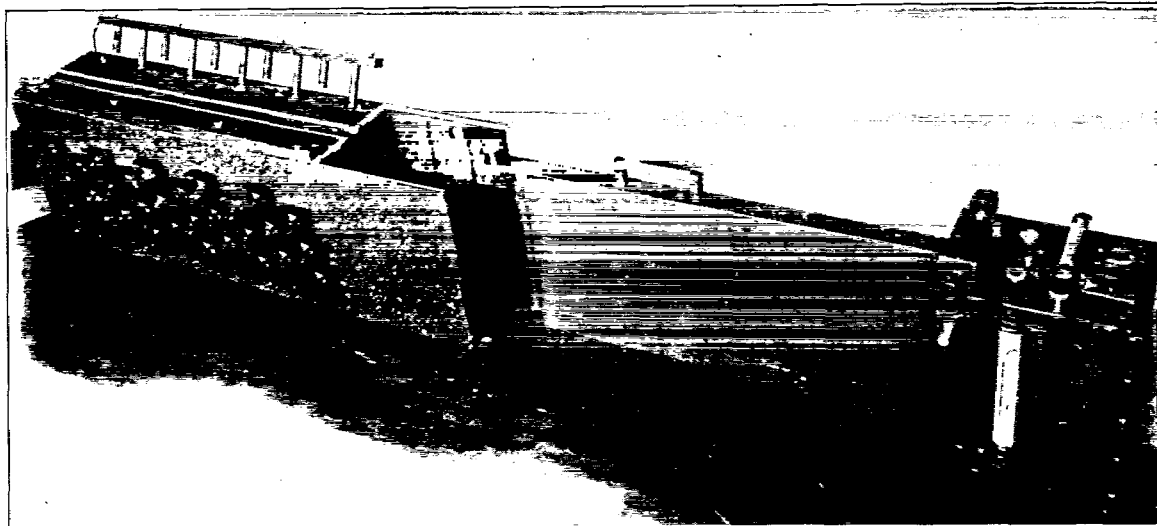
mounted on the control column. The instrument records were synchronized by means of timing lines placed simultaneously on all the records by an N. A. C. A. timer (Reference 5).

METHOD

Since only one manometer was available for these tests (two of the three type 60 manometers possessed by the N. A. C. A. being installed on another airplane), it was possible, in the

time allowed, to investigate the pressure distribution on only one-half of the horizontal tail surfaces in addition to that on the vertical surfaces. The right horizontal surfaces were therefore chosen because a previous investigation on a pursuit type airplane ("Pressure Distribution on the PW–9 Airplane," not yet published) indicated that down loadings are greater than up loadings, in general, and because the effect of the slip stream is to further increase the down loading on the right side. Since, therefore, the maximum loads are obtained on this side, the loads on the left surfaces are within the limits of the loads obtained.

Pressure measurements were made in level flight throughout the speed range; in a number of high-speed dives with stabilizer up, down, and neutral and with power on and off; in a series of abrupt pull-ups at different speeds; and in several of the common maneuvers such as the barrel-roll and tail spin. In addition to the above, two more unusual maneuvers, one of them quite unorthodox, were investigated with the object of obtaining high loads on the vertical surfaces. The first of these, or the "vertical reverse," as it is called in this report, was performed by throwing the airplane from a right or left vertical bank into a vertical bank in the opposite direction, the rudder being the principal control surface used in the maneuver. The second, or "rudder reversal," was made by kicking the rudder right or left while the ship was traveling at high speed, all other controls remaining neutral, and as the ship approached the position of maximum yaw, kicking full opposite rudder. Thus, the vertical surfaces were operating at a high angle of attack at high speed. This maneuver, while not ordinarily performed, probably imposes the highest possible loads on the vertical surfaces, and it is felt that the loads obtained can safely be used as a criterion of the maximum loads obtainable on the surfaces involved.

The pressures obtained were plotted on the chord of each false rib as a base line and curves were drawn through the ordinates giving the pressure diagrams as in Figure 5. In all cases, the difference in pressure between the upper and lower surfaces at each station was measured, no attempt being made to measure individual pressures on the upper or lower surfaces. Integration of the areas under the pressure curves gave the load per foot span and these latter values plotted along the span formed the ordinates of the span-loading curves which, integrated, gave the total loads over the surfaces. In some cases the rib pressure curves were cross-faired to give span-wise pressure curves from which the chord loading for the whole surface could be determined in the same manner as the span loading. Justification for plotting normal to the chord pressures which have been measured normal to the curved surface of an airfoil can be found in Reference 6.

Although the displacements of the controls were measured, they were neglected in working up the data except in the conditions of maximum load.

PRECISION

A number of possible sources of error are present in work of this nature. In tabular form they are as follows:

I. INDIVIDUAL PRESSURES

(a) Orifice cap not flush with surface.
(b) Tube stopped or leaking.
(c) Capsule calibration changed.
(d) Pressure loss in tube from orifice to manometer.
(e) "Personal equation" in plotting and reading calibration.
(f) Excessive width and haziness of record line caused by oil or dust on lens, small rapid pressure fluctuations due to local eddies, or vibration.
(g) Time lag due to length of tube and hysteresis in capsule diaphragm.
(h) Shrinkage of film.

II. RIB LOADS AND TOTAL LOADS

(a) Untrue pressure curves caused by errors in individual pressures.
(b) Plotting—personal errors.
(c) Fairing curves through relatively few points.
(d) Integrating—personal errors and necessity of using relatively small scale in plotting.
(e) Neglect of control surface displacement in plotting pressures on chord line.

The errors due to I(a) and I(b) are negligible. Frequent inspection showed no leaks or stoppages in the tubes, and care was taken to make the orifice caps flush with the surface. The duration of the testing period was so short that the capsule calibrations did not change except for a fraction of a per cent in a few cases (I(c)). The pressure loss in the tubes, I(d), arising from the interference of the pressure impulses within the tube, was less than 2 per cent inasmuch as the tube lengths did not exceed 10 feet (References 7 and 8). Errors due to I(e) were minimized by checking. It was found that two operators performing the same function checked each other within a half of 1 per cent. Errors due to I(f) are probably the greatest. In some cases the width of the line was as much as 7 or 8 per cent of the deflection. The mean of this line was always taken as the true line, of course, but as the edges were hazy, how close the mean line could be read is a matter of conjecture. It is probable that the readings are in error not more than 2 per cent from this cause. Time lag (Reference 8) and shrinkage of the film introduce negligible errors.

The principal source of error in the integrated results from the pressure curves is in the curves themselves. Personal errors in plotting and integrating were small, and as the ordinates of the curves, then, are the primary sources of error in the determination of loads, error in the total normal forces depends on the mean error of both the measured pressures and the interpolated pressures. This error is estimated to be within 4 per cent.

In general, then, individual pressures are probably correct to within ± 2 per cent while total loads are accurate within ± 4 per cent.

The error introduced by the displacement of the controls is variable. In this investigation the error is neglected in most cases, but this neglect always increases the force, which is on the conservative side. In the worst case, the error caused by the neglect of control displacement would have been 11.7 per cent had the displacement been neglected.

Air speed is correct to within ± 2 M. P. H. except in the dives, in which case the impact pressures were read on a flattening out portion of the calibration curve and can not be relied upon to within less than 6 M. P. H.

Accelerations are correct to within 0.1 g.

RESULTS

In the tables and pressure plots following, the directions of these pressures and of the loads and moments are in conformity with the standard system used by the National Advisory Committee for Aeronautics; that is, positive loads and pressures on the horizontal surfaces act upwards and positive pressures on the vertical surfaces act from right to left. Therefore, if the pressure or load diagram is plotted on the upper or left surface it is positive, and vice versa. All moments are given with reference to the hinge center lines as the most convenient data and are positive if clockwise when viewed by an observer at the left or from the top of the airplane.

The results are presented in Tables I and II and in Figures 5 to 29. Table I gives the loads, moments, and maximum pressures for the maneuvers investigated except the level flight runs which are omitted because the distribution is the same as in the dives, with pressures of less magnitude.

The most severe loads on the horizontal surfaces were found to occur in the pull-up. In this maneuver a peak down load is experienced which is followed closely by a peak up load of lesser intensity. This sequence always obtains in abrupt pull ups and can easily be explained. The heavy down load is, of course, induced by the sudden upward displacement of the elevator and causes the tail to swing down. The attitude is soon reached where the whole airplane is inclined at a large angle of attack, thus causing the resultant load on the tail surfaces to act upward. The action is so rapid on a highly maneuverable airplane of this type, the time between maximum down and up loads being of the order of a quarter of a second, that there would be no opportunity for the pilot to alter the phenomenon by easing the controls, and hence the condition may be considered entirely automatic and little affected by factors other than the aerodynamic and inertia properties of the airplane. The down loads on this airplane were always at least 100 per cent greater than the corresponding up loads. The values for both
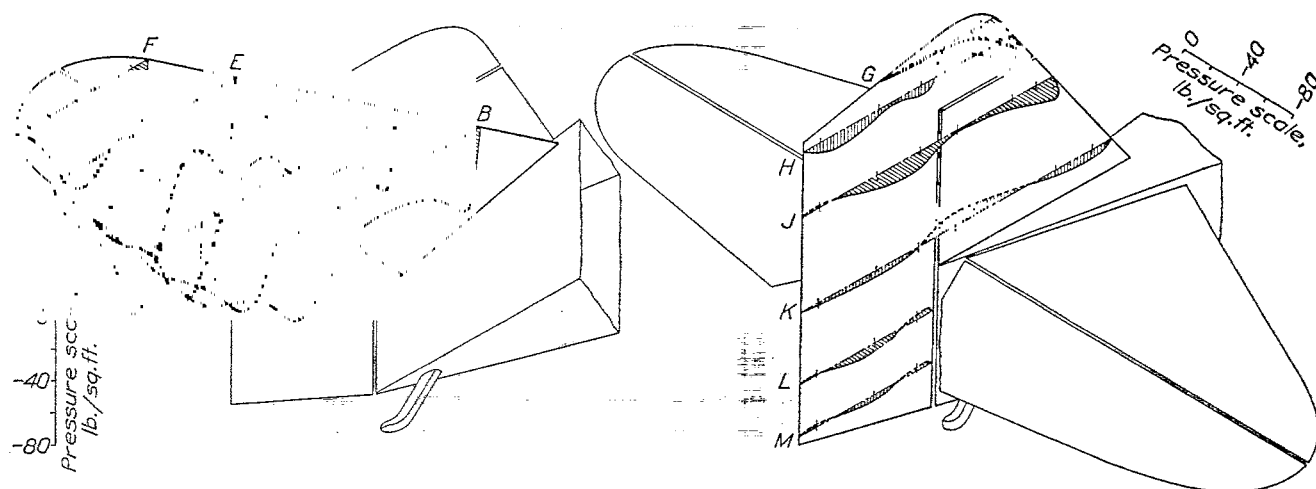
FIG. 5.—Pressure distribution in a pull-up at 163 M. P. H. Run No. 11

FIG. 6.—Pressure distribution in a dive at 247 M. P. H. Run No. 18

FIG. 7.—Pressure distribution in a right roll at 109 M. P. H. Run No. 57

FIG. 8.—Pressure distribution in a left spin. A. S.=43 M. P. H. Run No. 60

FIG. 9.—Pressure distribution in a left spin. A. S.=74 M. P. H. Run No. 61

FIG. 10.—Pressure distribution in a vertical reverse at 92 M. P. H. Run No. 62

conditions are given for illustration in Table I, Run No. 7. The maximum total load on the horizontal surfaces occurred in a pull-up at 163 M. P. H. In this maneuver, also, the maximum local pressure and the maximum loads on the stabilizer and elevator occurred simultaneously, the average loading being 34 pounds per square foot acting down. With respect to the load acting normal to the plane of the stabilizer, the tabulated value of −540 pounds
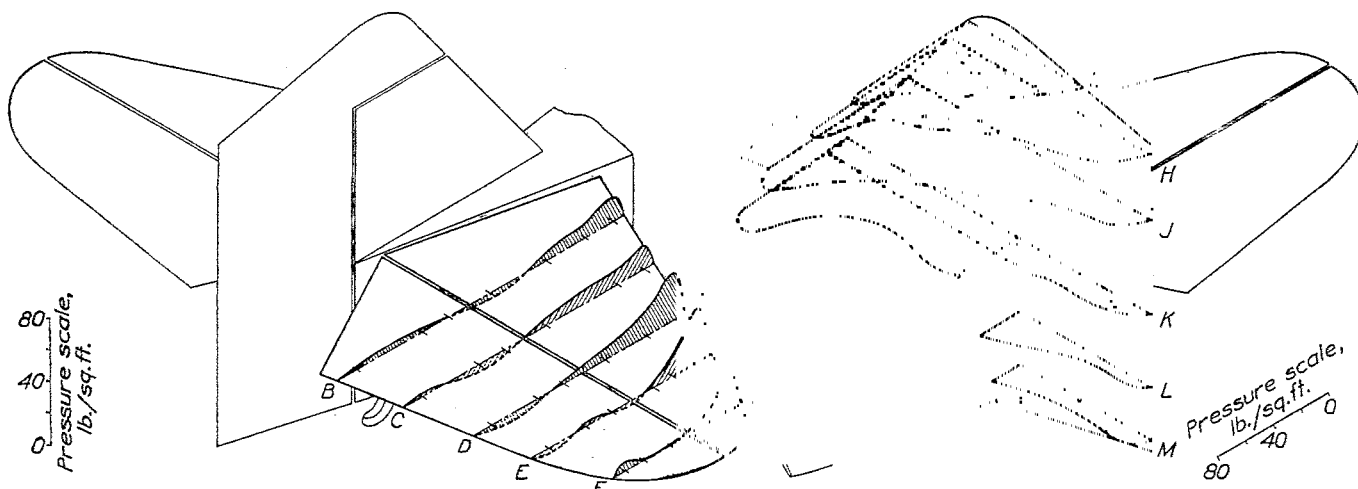
FIG. 11.—Pressure distribution in a rudder reversal at 153 M. P. H. Run No. 70 (a)

is not exact, the true force in this direction, taking into account the elevator angle, which in this case is 33.3°, being −490 pounds, while the component of force on the elevator parallel to the stabilizer chord is 160 pounds. In the pull-up at 173 M. P. H., although the acceleration obtained at the center of gravity was higher (fig. 29), the tail loading was less because the stick was not pulled back so sharply. There is no reason to suppose that had the maneuver been made in the same manner as the preceding ones the tail load would not have been greater.
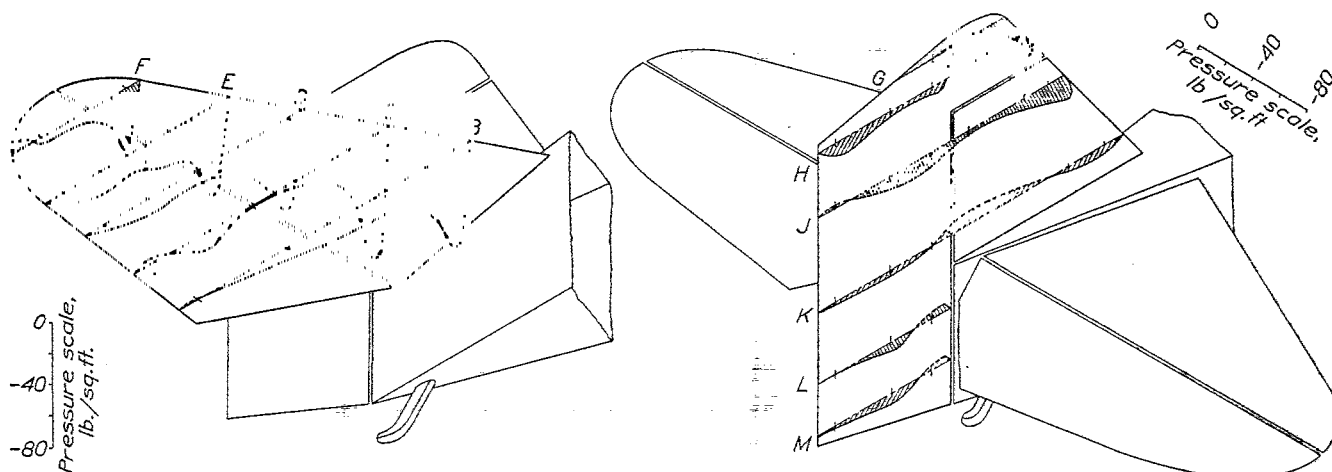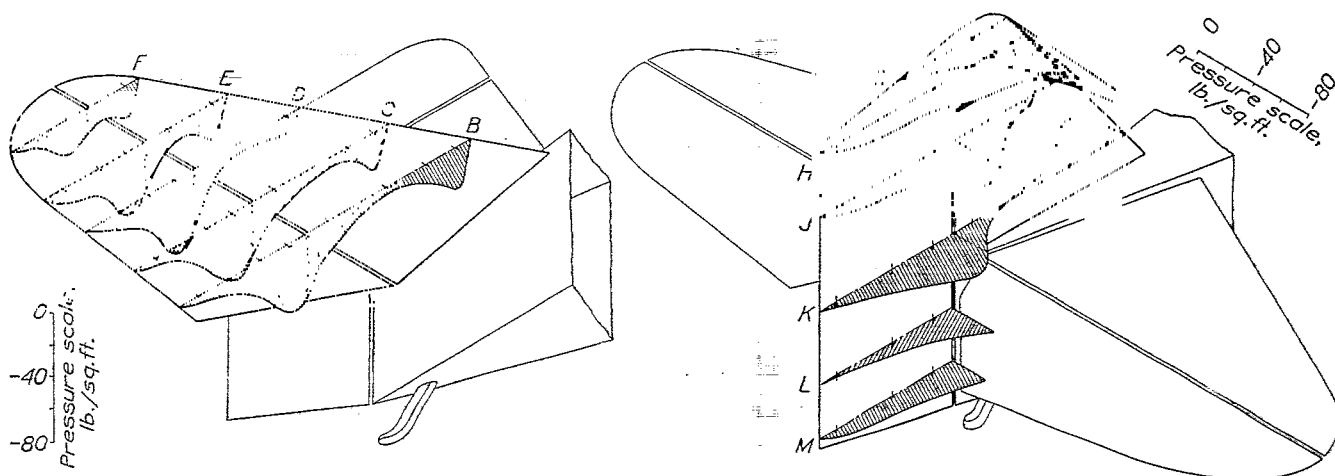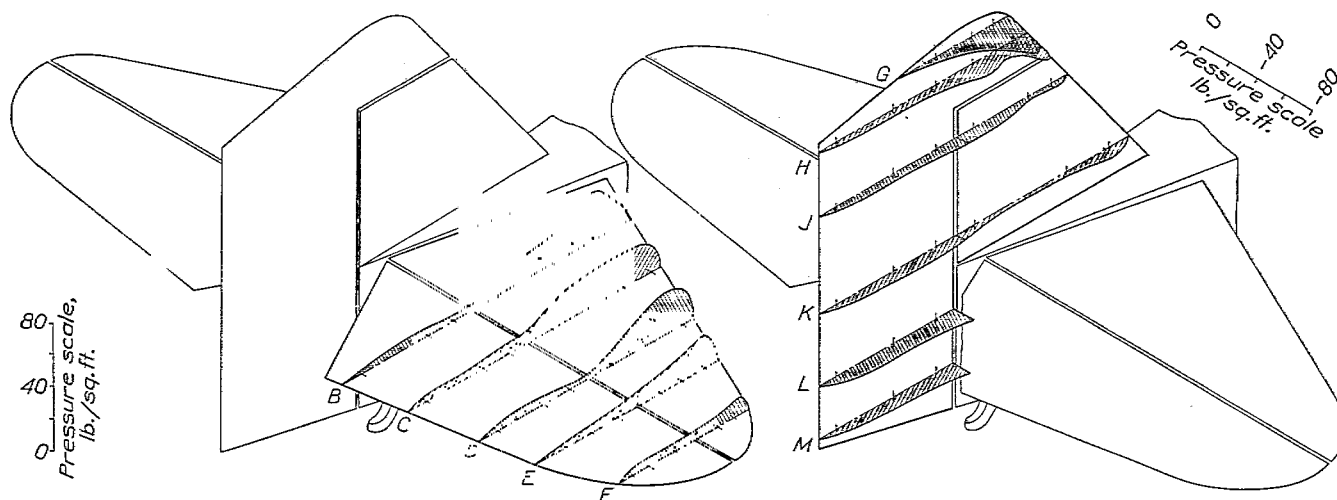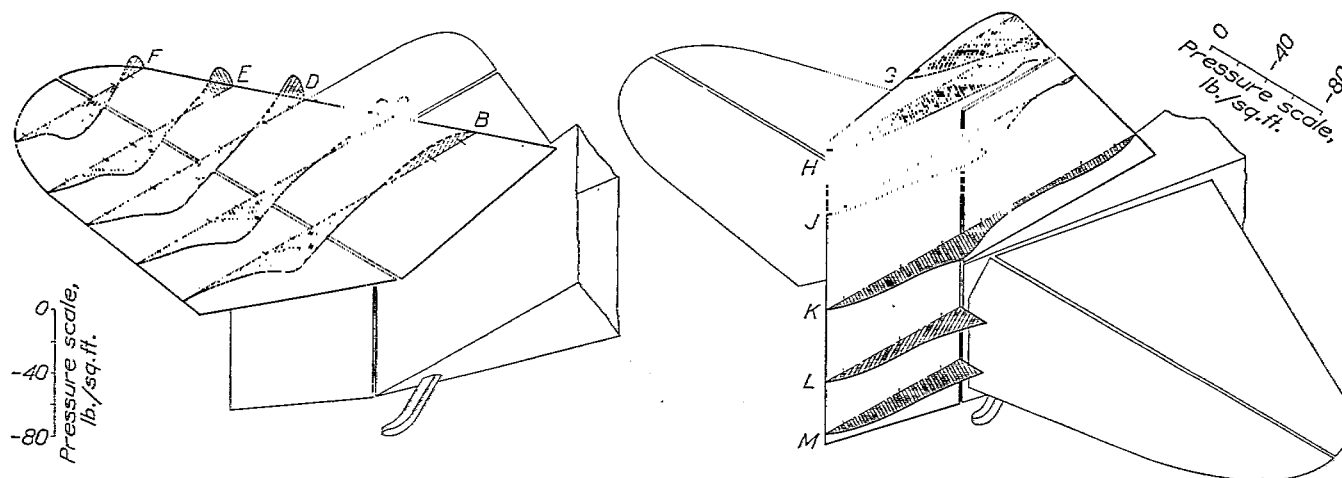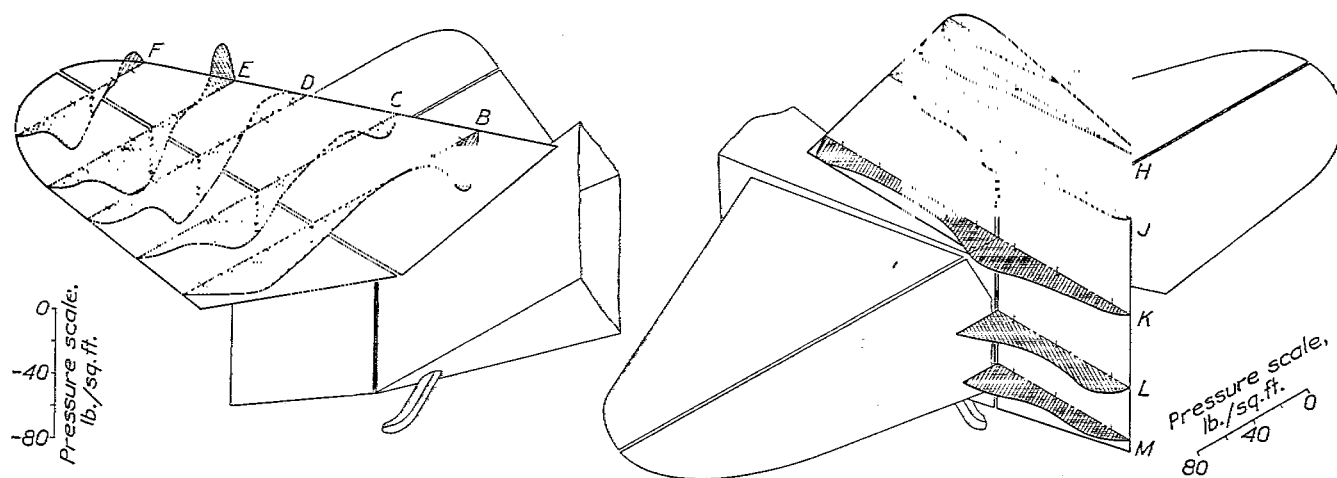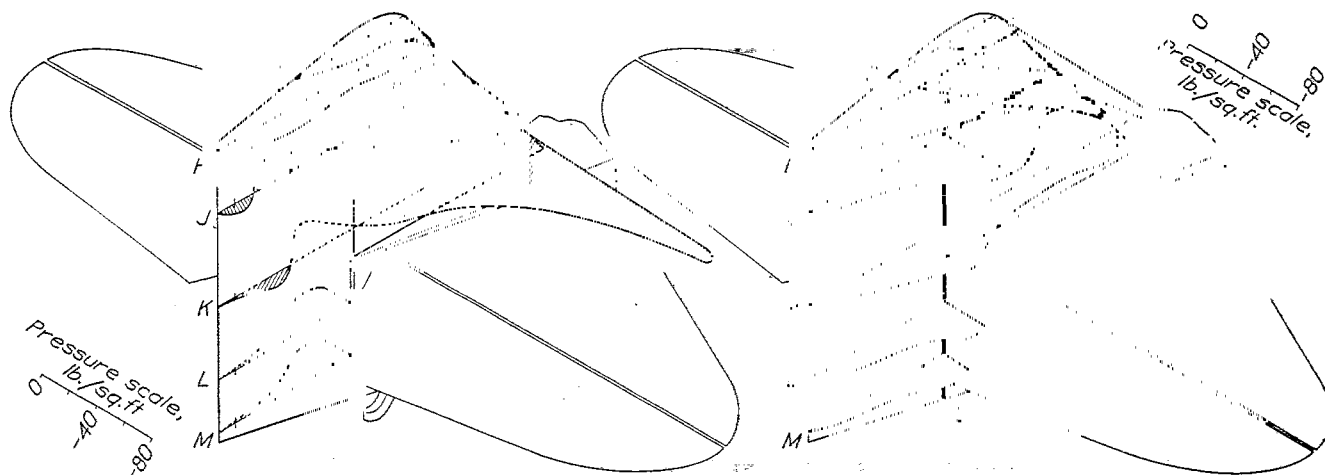

FIG. 12. Pressure distribution in a reversal at 153 M. P. H. Run No. 70 (b)   FIG. 13.—Pressure distribution in a reversal at 153 M. P. H. Run No. 70 (c)

The total loads in the dives were relatively small, although the leading edge pressures and stabilizer loads were high. Little difference existed with stabilizer neutral, up, or down and with power on and off. There is some doubt about the position of the stabilizer in the dives. Instructions were given to the pilot to set the stabilizer either up, down, or neutral, as indicated in Table I, but the control position recorder showed a variation of less than 1° from neutral, and it is probable that for some reason the pilot failed to follow instructions. The loads given are the maximum in each case, and the variations are probably due to impact with gusts of air
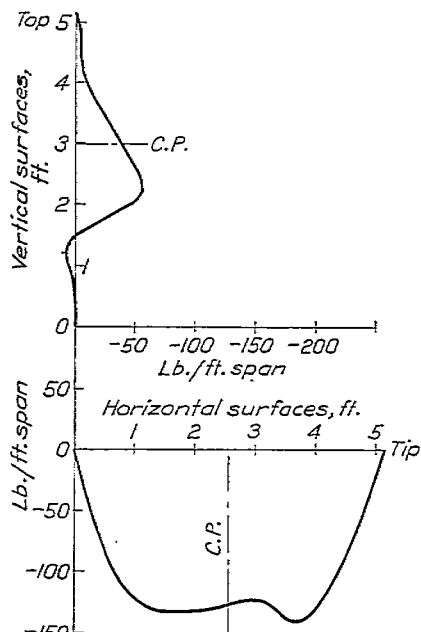
FIG. 14.—Pull-up at 163 M. P. H.   Run No. 11
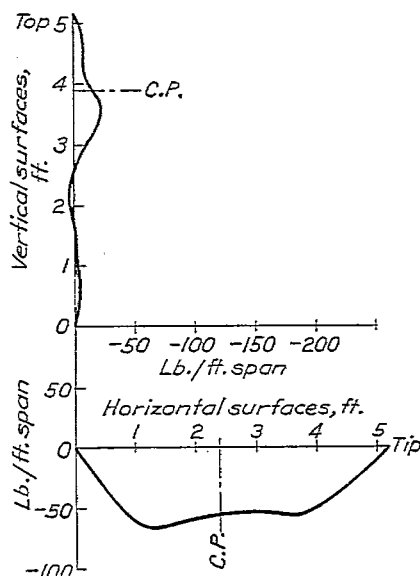
FIG. 15.—Dive at 247 M. P. H.   Run No. 18
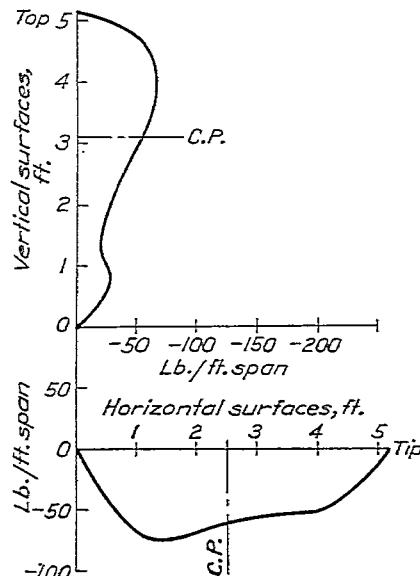
FIG. 16.—Right roll at 109 M. P. H.   Run No. 57
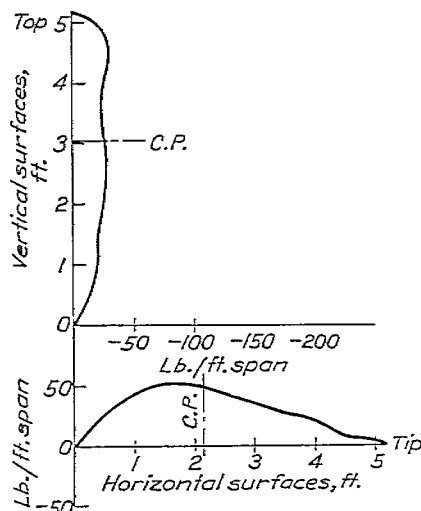
FIG. 17.—Left spin.   Run No. 60
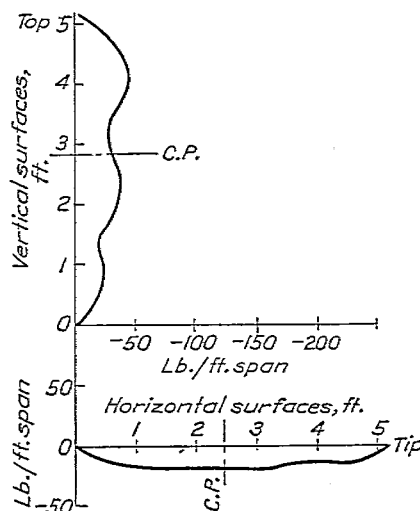
FIG. 18.—Left spin.   Run No. 61
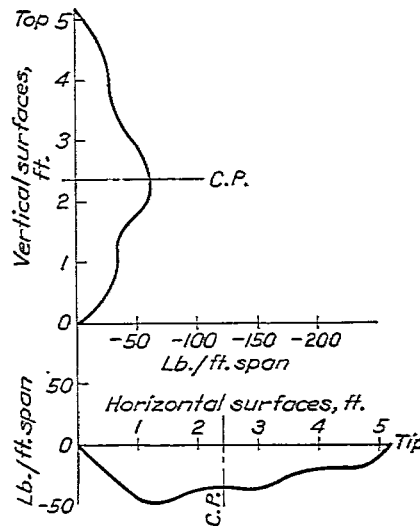
FIG. 19.—Vertical spin.   Run No. 62
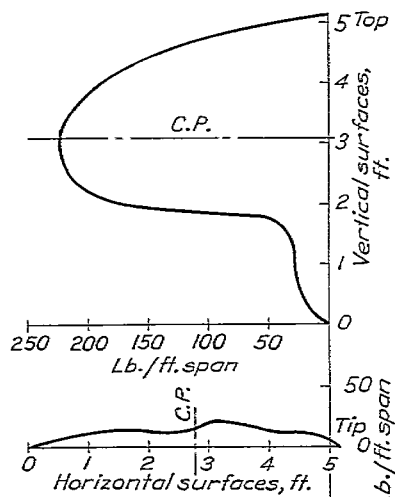
FIG. 20.—Rudder reversal.   Run No. 70 (a)
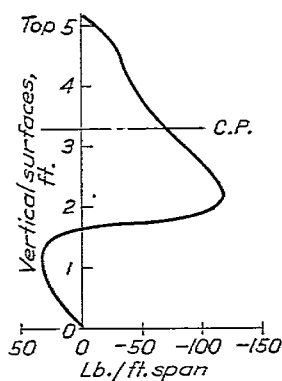
FIG. 21.—Rudder reversal.   Run No. 70 (b)
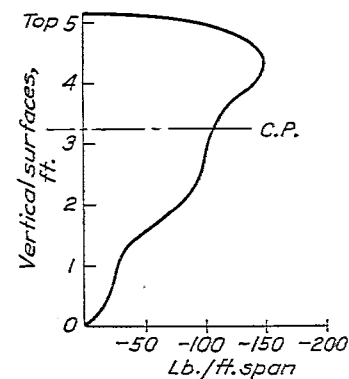
FIG. 22.—Rudder reversal.   Run No. 70 (c)

SPAN LOADING CURVES
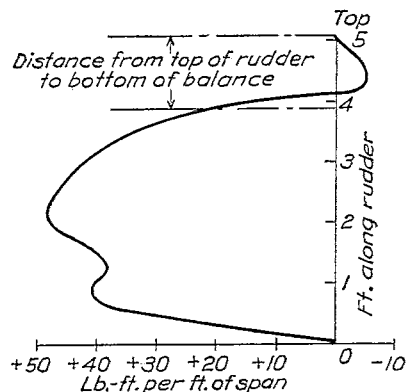
FIG. 23.—Half roll at 161 M. P. H.
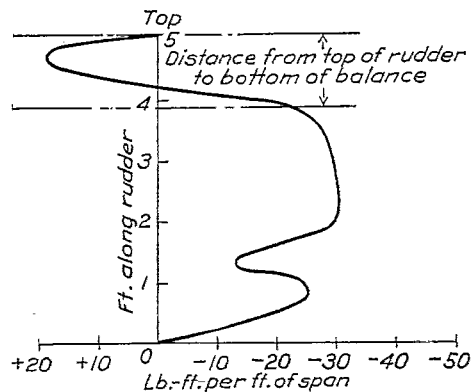
FIG. 24.—Right roll at 109 M. P. H.
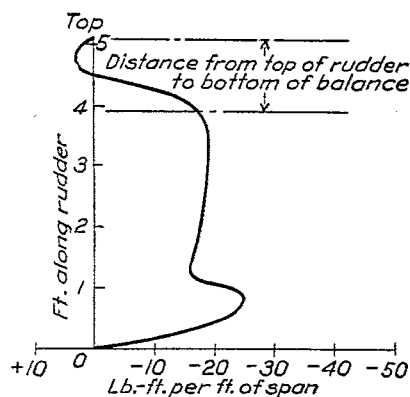
FIG. 25.—Left tail spin

FIG. 26.—Rudder reversal at 153 M. P. H.

Span-moment curves for the rudder showing effect of balance in reducing hinge moment
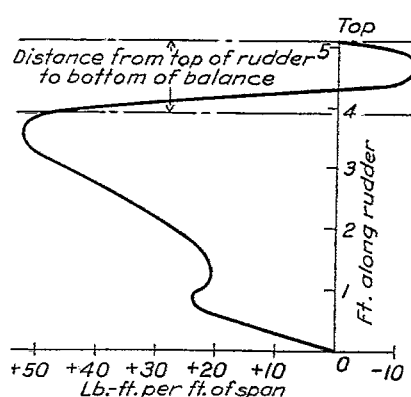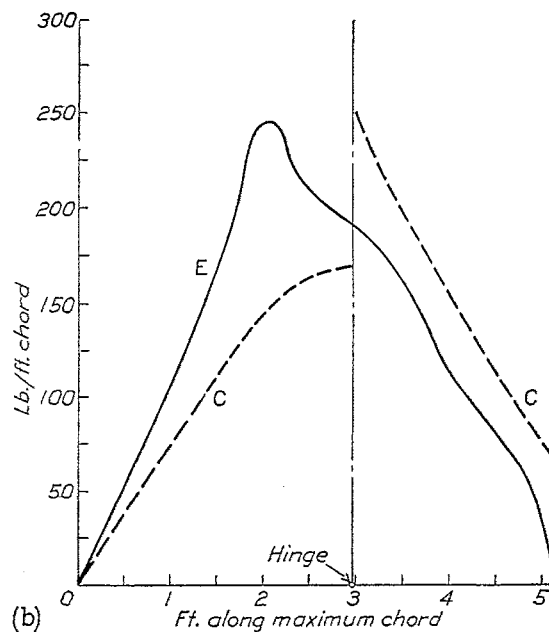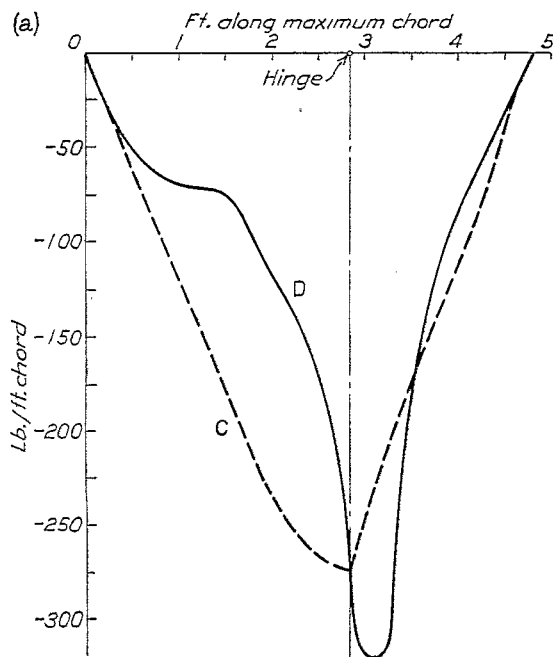
(a) Horizontal surfaces, Curve D: Chord loading in the condition of maximum total load on stablilzer and elevator. Run No. 11

(b) Vertical surfaces, Curve E: Chord loading in the condition of maximum total load on fin and rudder. Run No. 70

FIGS. 27 (a) and (b).—Comparison of chord loadings

Curve C: Chord loading obtained with surfaces loaded as specified for static tests

more than to any other cause. These gusts or bumps are quite noticeable in high-speed dives and produce accelerations of the order of 2.5 *g*. Table I, it will be noted, indicates down loads on the elevator in all of the dives investigated. This would imply that a pull back on the control column was necessary to hold the airplane in equilibrium and prevent it from going over on its back, which is contrary to normal experience. It is probable that the pilot set the stabilizer neutral for all of the dives (neutral being defined as the position at which the airplane is traimmed at cruising speed), which would really be a slight nose heavy condition for the
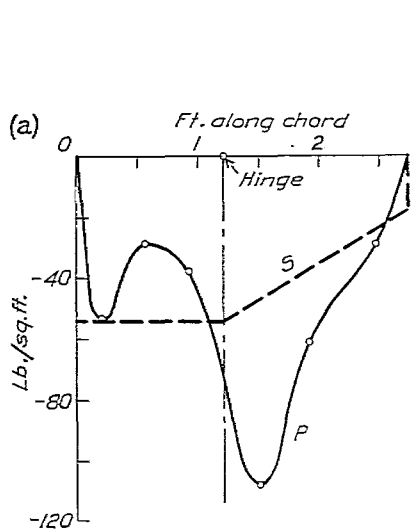
FIG. 28 (*a*).—Horizontal surfaces. Curve P: Pressure distribution on rib E in a pull-up at 163 M. P. H. Curve S: Specified loading
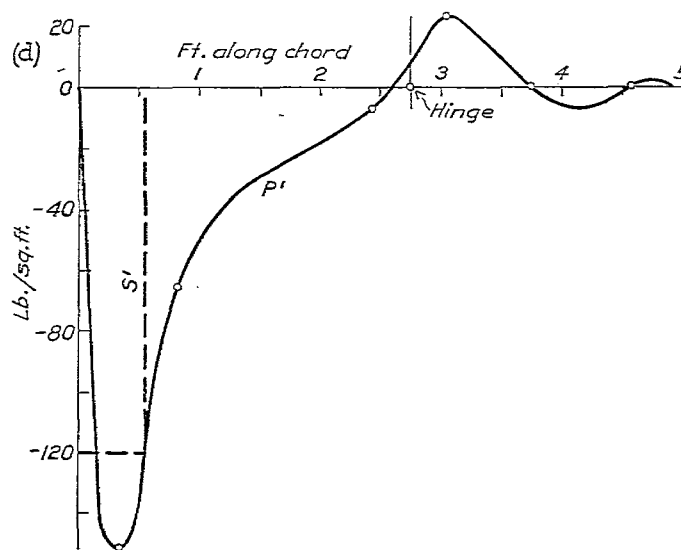
FIG. 28 (*d*).—Vertical surfaces. Curve P': Pressure distribution on rib K in a rudder reversal at 153 M. P. H. Curve S': Specified leading edge loading
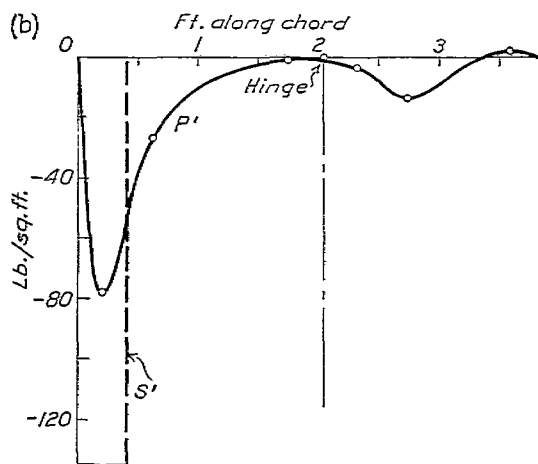
FIG. 28 (*b*).—Horizontal surfaces. Curve P': Pressure distribution on rib C in a dive at 247 M. P. H. Curve S': Specified leading edge loading
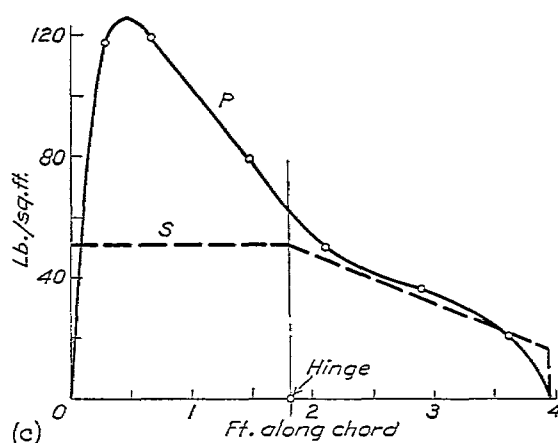
FIG. 28 (*c*).—Vertical surfaces. Curve P: Pressure distribution on rib J in a rudder reversal at 153 M. H. P. Curve S: Specified loading

OBSERVED RIB LOAD DISTRIBUTION COMPARED WITH SPECIFIED LOAD DISTRIBUTION ALONG THE CHORD

airplane with normal location of the center of gravity. (See description of airplane on p. 4.) This would explain the pull-back on the control column, and would mean, too, that the interpretation of the results for the dives should take into consideration that with the stablizer set down, or tail heavy, as it usually is set in the diving condition, the pressures near the leading edge would be somewhat greater, and the load on the elevator would be reversed in direction, although probably still small in magnitude.

Loads on the horizontal surfaces in the rolls, spin, and vertical reverse and in the rudder maneuvers are comparatively small.

The rudder reversal, as has been stated, is probably the most critical maneuver with reference to the vertical surfaces. In the rudder reversal at 153 M. P. H., the average loading on the vertical tail surfaces was equal, within the experimental error, to the design specification of 40 pounds per square foot. In this case, the maximum load was experienced after the tail swung through zero yaw on the return journey with the rudder practically neutral. Thus, the load given is the true load and requires no correction for control displacement. On the same rudder reversal, at a different part of the maneuver, a maximum pressure of -151 pounds per square foot was experienced on the fin at K-I, which exceeds the leading edge specified
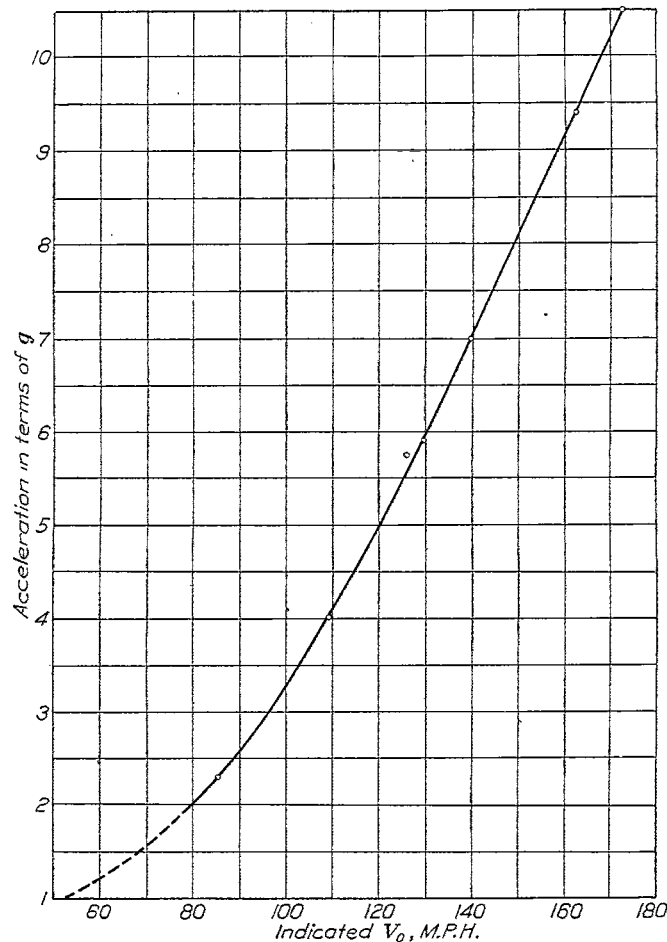
Fig. 29.—Accelerations against V_θ for the F6C-4 airplane in pull-ups

loading at this point. Loads on the balance of the rudder were high in this maneuver, the maximum pressure being 122 pounds per square foot at G-I.

All other loads and pressures on the vertical surfaces were relatively small.

It should be pointed out here again that the rudder reversal is a very unusual maneuver, and, since it imposes extremely high loads on the structure, could very well be prohibited in military maneuvers, particularly inasmuch as it has no known usefulness. It is probable, though, that the distribution obtaining here is similar to that in any other maneuver involving high speed and high angle of attack of the vertical surfaces, such as in a bad side slip. For immediate purposes of design, however, it would probably be better to consider as the worst loads those occurring in the rolls. It will be noted that the loads in the half roll given in Table I are higher than those given for the roll, but the distribution is almost exactly similar for both, the difference being in magnitude only, which would be still different for rolls or half rolls at different speeds.

Pressure curves for several of the more interesting cases are plotted in Figures 5 to 13. The corresponding pressures are tabulated in Table II. Run numbers are given in each case so that the curves and tables can be interconnected readily. The appendices (a), (b), and (c) of Run No. 70 refer to different parts of the same maneuver, not necessarily in chronological order, but in the order of their importance.

Figures 14 to 22 give the span-loading curves for these conditions and are drawn as if viewed from behind the airplane. The load is rather symmetrically disposed on the horizontal surfaces in spite of the considerable taper, which indicates a greater intensity of loading near the tip. The span-loading curves are particularly useful in that they show the lateral and vertical locations of the center of pressure on the horizontal and vertical surfaces, respectively.

Figures 23 to 26 are "span-moment" diagrams for the rudder in several maneuvers in which the rudder moments were high. The curves were constructed from the pressure curves by plotting the moment for each rib, obtained during the integration, along the height of the rudder. The effect of the balance in reducing the rudder hinge moment is shown clearly, and if the curves be faired approximately as they would be if there were no balance present, it will be seen that the difference in area is around 25 per cent. This indicates that the balance could be enlarged without danger of the rudder taking control at the larger angles.

Figure 27 shows the chord-loading curves for the maximum loads on the horizontal and vertical surfaces, respectively, compared with the chord-loading curves obtained with the surfaces loaded as for static test. They indicate that the elevator and fin were overloaded in flight. A glance at the curves discloses that the centers of pressure are both very near the hinge center line, which suggests that the present method of assuming the maximum vertical and horizontal tail surface loads to act at the rudder post in the fuselage analysis is very close to the true conditions.

Several individual chord-pressure curves which indicate high local rib loads and pressures, are compared with the specified loading diagram for these ribs in Figure 28. It will be seen that the measured loads on the elevator greatly exceed the specified, while the stabilizer loads are not dangerous. The rib loading on the unbalanced portion of the rudder in the worst case is about equal to the specified loading and the distribution is very nearly the same. Leading edge pressures on the fin are high and may exceed the specified leading edge load.

When any of the results given herein are compared with the existing specifications, it should be borne in mind that a factor of safety of two is intended to be implied in the latter. Therefore, any load in a legitimate maneuver that exceeds half the design specifications is an indication that the specifications are low.

The curve of accelerations vs. initial air speed for the pull-ups is given in Figure 29. The accelerations show no tendency to fall off as the higher values are approached and it seems evident that it would be quite possible to break the airplane in the air. The "theoretical" acceleration curve (based on the formula $a = \dfrac{V_0^2}{V_s^2}$, where V_0 is initial air speed and V_s the stalling speed) is not included because the stalling speed of the airplane is not known accurately enough to give a quantitative comparison. However, if a stalling speed of 52.5 M. P. H. be assumed and the theoretical curve plotted, it will be seen that the two curves practically coincide in the range of accelerations measured.

Although the results obtained in these tests are of great value in that they indicate that certain revisions in the design specifications would be desirable, it must not be forgotten that the study of the loads that are likely to be experienced on tail surfaces involves far more than the experimental determination of such loads on one particular airplane. Even the results obtained on one airplane of a particular type are not strictly applicable to other airplanes of the same type, since a considerable number of variables are concerned, the alteration of any one of which will affect the magnitude and distribution of the loads in question. For instance, in steady flight the loads on any combination of horizontal surfaces will vary with the stability characteristics of the wing, the position of the center of gravity, the fuselage length and shape, and the drag-thrust couple. Then, for any given combination of these variables, the load

distribution will change with the tail airfoil section, the plan form, and the slip-stream characteristics at the tail. In accelerated flight conditions are different in that the loads are affected mainly by the resistance of the airplane to rapid changes of direction (exclusive of the stabilizing effect of the tail). It can be seen, therefore, that the present investigation supplies only a relatively small amount of the information that will be necessary before really satisfactory load specifications can be drawn up.

EFFECT OF ACCELERATIONS ON THE PILOT

An important though incidental result of these tests is the reaction of the pilot to the instantaneous acceleration of 10.5 g. obtained in the sharp pull-up at 173 M. P. H. It has long been a moot question among aeronautical engineers as to whether the design load factor for pursuit airplanes is now set at the proper value, and if not, what the limiting consideration in its determination should be. There have been some attempts to determine the proper load factors for different types from theoretical considerations based on weight and speed range, but the experimental evidence to date (Figure 29, for instance) indicates that for pursuit type airplanes, at least, it is quite possible to break the airplane in the air unless the load factor is made unduly high or the control limited to prevent abrupt maneuvers. Performance in its broad sense is reduced by both of these expediencies. If, however, the physical resistance of the pilot is the limiting factor, there is no need to curtail performance by overstrengthening the airplane structure or by reducing the control.

It has been generally accepted heretofore that instantaneous accelerations as high as 7.8 g. cause the pilot no discomfort while "accelerations of the order of 4.5 g., continued for any length of time, result in a complete loss of faculties" (Reference 9). This belief has been supported by tests at Langley Field in which short-period accelerations up to 9 g. caused no considerable physical reactions. The acceleration of 10.5 g., however, resulted in the condition described below, and it seems evident that the limit is being approached. It is not wise, of course, to make conclusions from one instance, but the question would seem to be of considerable importance and warrants further investigation.

The statement of Captain Peak, of the Army Medical Corps, with reference to the case mentioned follows:

STATION HOSPITAL, LANGLEY FIELD, VA.,
June 8, 1928.

Memorandum to: Richard V. Rhode, N. A. C. A.
Re: Luke Christopher, captain, Air Corps Reserve (N. A. C. A. Pilot).

In September, 1927, Captain Christopher came to the hospital for treatment. On examination he showed a generalized conjunctivitis of both eyes. He also showed generalized systemic neurological symptoms leading me to think that he had a mild cerebral concussion with some generalized cerebral capillary hemorrhage or at least a marked degree of passive traumatic enlargement. Being interested in the case, I wrote complete descriptions to Doctor Schneider, of Wesleyan University, and to Dr. L. H. Bauer, of the Department of Commerce. Both of them agreed with my opinion of the cause and nature of this condition, namely, it was due to sudden changes of centrifugal force while doing high-speed flying in acceleration tests. There was a duty recovery from this condition in about two weeks and a complete recovery in about a month.

I. F. PEAK,
Captain, Medical Corps.

CONCLUSIONS

It is concluded from these tests that:

1. The average loading obtainable on the horizontal tail surfaces in maneuvers involving principally the use of the elevator exceeds half the specified loading, except at very low speeds and in cases where the elevator is used cautiously. Thus, the material factor of safety in these maneuvers is less than two (on the basis of the design specifications and without considering relative distributions), indicating that the specified value of average load should be raised. Also, provision should be made in the specified distribution to take care of the high loads existing on the elevator.

2. The specified average loading on the vertical tail surfaces is probably satisfactory for all legitimate maneuvers, but the specified distribution should be changed to throw the predominance of load on the rudder, except for special leading edge loads.

3. Loads on the balanced portion of the rudder are severe, but with a balance of the size used here they do not approach a value sufficient to balance the loads on the rest of the rudder.

4. Accelerations of the order 10.5 g. may cause serious physical disorders in the pilot, and it is recommended that the effect of accelerations upon the pilot be investigated thoroughly by the Army or Navy Medical Corps in conjunction with the National Advisory Committee for Aeronautics or some other agency in a position to measure accelerations in flight.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY,
    NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
        LANGLEY FIELD, VA., *July 9, 1928.*

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APPENDIX

The Navy requirements for the strength of tail surfaces are given in the following specification excerpted from "General Specification for the Design of Airplanes for the United States Navy," SD–24–B (the specifications of the Army Air Corps are in exact agreement with these):

STRENGTH

365. The strength of the tail group shall be demonstrated by static tests to destruction.

366. The design loads for tail surfaces shall be in accordance with Table I.

(Table I gives average loading in pounds per square foot for the horizontal and vertical surfaces of single-seater fighters as 45 and 40, respectively.)

367. The load is to be distributed uniformly over the fixed surface, but for movable surfaces the intensity of loading at the hinges shall be equal to the loading on the fixed surface in front of it and shall decrease uniformly to an intensity of one-third this value at the trailing edge. Portions of the movable surface in front of the hinges shall carry the same loading as the fixed surface. This includes surfaces which are balanced by auxiliary vanes.

368. When auxiliary vanes are used for balancing, they shall be assumed to be subject to the same intensity of loading as the fixed surfaces, when computing the distribution of load and the stresses in the remainder of the movable surface. The vanes themselves and the attachment to the main movable surface shall be strong.enough to carry the load required to balance the load on the main portion of the movable surface.

369. The control surfaces must be designed to carry the specified load acting in either direction.

370. Although no load parallel to the chord of the fixed tail surfaces, or torsional load, is specified, provision shall be made to carry a reasonable amount of such load.

371. To determine the unit loading on the fixed surface with trailing control surface, use the following formula:

$$X = \frac{Specified\ average\ loading \times (A_f + A_c + A_b)}{A_f + \frac{2}{3}A_c + A_b}$$

Where X = unit loading on fixed surface.

A_f = area fixed surface.

A_c = area control surface behind hinges.

A_b = area control surface in front of hinges.

372. In case the control surface is acting alone—i. e., not behind a fixed surface, design for the average load specified above—the distribution is to be uniform from the leading edge to the hinge and from the hinge to the trailing edge shall vary uniformly to one-third this value.

LEADING EDGE TEST

373. The stabilizer and fin shall be subjected to leading edge tests. In these tests the surfaces shall be supported at the fuselage and at the hinges along the rear stabilizer beam or the rear fin post. The load shall be uniformly distributed (in pounds per square foot) along the span of the surface and from the leading edge back 20 per cent of the chord of the fixed surface. The intensity of the loading shall be three times the average load specified for the design of horizontal and vertical tail surfaces, respectively.

TABLE I.—MAXIMUM LOADS, MOMENTS, AND PRESSURES

Run No.	Maneuver	Initial air speed	Total normal force	Total moment about hinge	Average loading	Stabilizer load	Elevator load	Elevator hinge moment	Maximum pressure	Location of maximum pressure	Total normal force	Total moment about hinge	Average loading	Fin load	Rudder load	Rudder hinge moment	Maximum pressure	Location of maximum pressure
		M.P.H.	Lbs.	Lb./in.	Lbs./sq.ft.	Lbs.	Lbs.	Lb./in.	Lb./sq.ft.		Lbs.	Lb./in.	Lb./sq.ft.	Lbs.	Lbs.	Lb./in.	Lb./sq.ft.	
3	Pull-up	86	−337	110	−21.2	−148	−189	1,500	−46	D-4	62	−610	4.0				97	K-1
6	do	109	−388	−180	−24.4	−172	−216	1,600	−68	D-4	78	−720	5.0				26	J-1
7	do	126	−468	−780	−29.4	−224	−244	1,760	−86	E-4								
7	do	126	+202	2,900	12.7	186	16		74	E-1								
10	do	140	−481	−180	−30.2	−221	−260	1,920	−93	E-4								
11	do	163	−540	−680	−34.0	−245	−295	2,010	−108	E-4	−100	1,100	6.4				−33	K-1
16	do	173	−422	380	−26.5	−170	−252	1,700	−89	E-4	243	−530	−15.6				38	K-1
17	Dive, n[1], power on	[2]225	−244	−2,430	−15.3	−192	−52	360	−78	C-1	−34	340	−2.2				−31	G-1
18	do	[2]247	−234	−2,420	−14.7	−189	−45		−78	C-1	−37	−120	−2.4				−29	G-1
19	Dive, n, power off	[2]250	−242	−2,680	−15.2	−198	−44		−76	C-1	−41	440	−2.6				−33	G-1
20	Dive, u, power on	[2]253	−205	−2,140	−12.9	−159	−46		−71	C-1								
21	Dive, d, power on	[2]247	−212	−2,900	−13.3	−188	−24		−73	C-1	−22	30	−1.4				−28	G-1
35	Right rudder kick	166	−137	−970	−8.6				−41	B-1	260	550	16.7	72	188	1,190	55	G-1
48	Left rudder kick	128	−35	660	−2.2				−16	B-5	406	−2,850	26.0	111	295	1,420	49	K-4
51	do	169	−81	−470	−5.1				−18	D-4	−339	−570	−21.7	−67	−272		−107	G-1
54	Half roll	161	−220	−860	−13.8	−130	−90	700	−37	B-1	315	1,320	−20.2	63	252	1,740	71	K-4
57	Right roll	109	−266	−90	−16.7	−107	−159	970	−46	D-4	−198	−1,420	−12.7	−7	−191	−990	92	G-1
61	Left spin	[2]74	−73	930	−4.6	4	−77	470	−22	D-4	−143	−600	−9.2	−27	−116	−876	−26	G-1
62	Vertical reverse	92	−148	500	−9.3	−35	−113	820	−35	D-4	164	530	10.5	40	124	900	25	L-1
70(a)	Rudder reversal	153	65	940	4.1				34	E-1	630	−3,890	40.4	336	294	1,460	117	J-1
70(b)	do	153									−180	4,430	11.9	−212	32		−151	K-1
70(c)	do	153									−396	600	25.4	−94	−302		−122	G-1

[1] n, u, and d (stabilizer neutral, up, and down). [2] Air speed at the time corresponding to loads given.

TABLE 11.—LOCAL PRESSURES ON F6C–4 TAIL SURFACES IN POUNDS PER SQUARE FOOT

Run No. 11   Maneuver: Pull-up   Initial A. S. 163 M. P. H.

Condition represented: Maximum load and pressure on horizontal surfaces

Rib	Orifice	Horizontal surfaces					Vertical surfaces					
		B	C	D	E	F	G	H	J	K	L	M
	1	−46.8	−45.3	−44.3	−53.6	−41.6	−8.3	−5.2	−20.8	−33.3	+7.8	+4.7
	2	−28.6	−19.2	−23.4	−28.6	−38.0	+4.2	−2.1	−10.9	−24.4	+4.2	
	3	−19.8	−33.3	−37.4	−38.0	−54.6	0	+7.3	−2.6	−8.3	0	−1.0
	4	−32.2	−68.7	−83.4	−108.2	−25.0		−5.2	−9.4	−10.9		
	5	−54.6	−48.8	−48.8	−60.8	−5.2		−1.6	−4.2	−2.6		
	6	−34.8	−16.6	−17.7	−28.6			−5.7	−.5	−3.7		
	7	−10.4										

Run No. 18.   Maneuver: Dive   Actual A. S. 247 M. P. H.

Condition represented: Representative

Orifice	B	C	D	E	F	G	H	J	K	L	M
1	−60.8	−78.0	−57.2	−57.2	−39.0	−28.6	−15.6	−15.6	−3.6	+2.6	+2.6
2	−27.0	−26.0		−26.0	−18.2	+2.6	−1.5	−8.8	−3.1	−5.2	
3	−14.0	−1.0	−11.4	−20.8	−5.2	0	+13.0	−1.5	+7.8	0	+1.0
4	−13.0	−3.6	−8.3	−13.0	−3.6		−5.2	−6.7	0		
5		−12.4	−11.4	−15.6	+5.7		−2.6	−10.4	−2.6		
6	−5.2	−2.6	−4.1				−8.8	+1.0	−1.0		
7	0										

Run No. 57.   Maneuver: Right roll   Initial A. S. 109 M. P. H.

Condition represented: Peak loads in a roll

Orifice	B	C	D	E	F	G	H	J	K	L	M
1	−26.0	−23.4	−12.0	−22.9		−92.0	−52.0	+8.3	+30.2	−22.9	−20.8
2	−12.5	−7.8	−7.8	−10.4	−14.1	−41.6	−33.8	−4.2	+10.4	−9.4	−8.8
3	−5.2	−17.7	−14.0	−14.1	−22.9	−12.5	−26.0	−22.4	−10.9	−1.0	
4	−22.4	−41.0	−45.8	−39.5			−20.8	−41.6	−36.4		
5	−41.6		−21.8	−17.7	−3.1		−13.5	−16.1	−22.9		
6	−21.8	−4.2	−5.7	−8.8			−8.8	−7.8	−5.2		
7	−4.2										

Run No. 61.   Maneuver: Left spin   A. S. 74 M. P. H.

Condition represented: Peak load on vertical tail surfaces in a spin

Orifice	B	C	D	E	F	G	H	J	K	L	M
1	+5.2	+16.7	+20.8	+17.2		−26.0	−19.8	0	−4.2	−14.1	−15.6
2	+8.3	+5.2	+3.6	+3.1	−4.8	−20.8	−15.6	0	−5.2	−9.3	
3	+1.0	−7.8	−9.3	−3.6	−17.7	−12.4	−17.7	−12.4	−6.8	−5.7	−7.3
4	−9.3	−21.3	−21.9	−18.2	−5.7		−15.6	−18.2	−16.1		
5	−20.3		−16.1		−1.0		−13.0	−10.9	−11.4		
6	−10.4	−3.1	−3.6	−4.2			−6.2	−5.2	−5.2		
7	−1.6										

Run No. 62   Maneuver: Vertical reverse   Initial A. S. 92 M. P. H.

Condition represented: Peak loads on horizontal and vertical surfaces in vertical reverse

Orifice	B	C	D	E	F	G	H	J	K	L	M
1	−32.2	−10.4		+28.6		+14.6	+18.2	−10.4	+17.7	+24.5	+22.4
2	−5.2	+4.2	+11.4	0	−2.6	+10.4	+14.6	+7.3	+9.9	+13.5	
3	0	−12.0		−7.8	−28.1	+5.2	+14.6	+9.9	+14.0	+16.1	+9.4
4	−10.4	−28.6	−35.4	−34.3	−8.3		+7.8	+20.8	+23.4		
5	−20.8		−15.6		−3.1		+5.2	+8.3	+14.0		
6	−15.6	−4.7	−9.4	−7.3			0	+5.7	+6.8		
7	−6.2										

TABLE II.—LOCAL PRESSURES ON F6C-4 TAIL SURFACES IN POUNDS PER SQUARE FOOT—
Continued

Run No. 70(a).   Maneuver: Rudder reversal   Initial A. S.   153 M. P. H.

Condition Represented: Maximum total load on vertical surfaces; maximum load on fin

Rib		Horizontal surfaces					Vertical surfaces					
		B	C	D	E	F	G	H	J	K	L	M
Orifice	1	+15.6	+15.1	+28.6	+34.3	+29.1	+31.2	+102.0	+117.5	+93.0	+31.2	+19.2
	2	+8.8	+9.4	+15.6	+13.0	+8.8	+71.3	+80.6	+118.6	+61.3	+18.7	
	3	+4.2	+4.7	+6.7	+3.6	+1.6	+49.4	+68.0	+78.0	+48.3	+10.4	+13.5
	4	-3.1	-2.6	+1.6	0	0		+65.0	+49.4	+32.2		
	5	0	-4.2	-1.6	+1.6	+5.7		+53.0	+34.8	+17.7		
	6	+2.1	+1.0	-2.1	-3.1			+27.6	+19.8	+9.4		
	7	+1.6										

Run No. 70(b).   Maneuver: Rudder reversal   Initial A. S.   153 M. P.H.

Condition represented: Maximum pressure on fin

							G	H	J	K	L	M
Orifice	1						-31.2	-19.7	-59.8	-151.0	+24.4	+23.4
	2						-10.4	-8.3	-51.5	-65.5	+10.9	
	3						-10.4	-12.5	-26.0	-6.8	+3.6	+2.6
	4							-9.9	0	+23.4		
	5							-14.6	+18.2	0		
	6							-9.3	-6.8	0		
	7											

Run No. 70(c).   Maneuver: Rudder reversal   Initial A. S.   153 M. P. H.

Condition represented: Maximum load and maximum pressure on rudder

							G	H	J	K	L	M
Orifice	1						-122.3	-98.9	-47.8	-14.6	-34.3	-22.9
	2						-80.2	-84.3	-22.4	-15.1	-16.1	
	3						-56.3	-60.3	-46.8	-20.8	-8.8	-6.2
	4							-44.7	-44.7	-36.4		
	5							-33.8	-19.2	-23.4		
	6							-14.0	-7.8	-7.8		
	7											